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LDRD final report for improving human effectiveness for extreme-scale problem solving: assessing the effectiveness of electronic brainstorming in an industrial setting

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Abstract

An experiment was conducted comparing the effectiveness of individual versus group electronic brainstorming in order to address difficult, real world challenges. While industrial reliance on electronic communications has become ubiquitous, empirical and theoretical understanding of the bounds of its effectiveness have been limited. Previous research using short-term, laboratory experiments have engaged small groups of students in answering questions irrelevant to an industrial setting. The present experiment extends current findings beyond the laboratory to larger groups of real-world employees addressing organization-relevant challenges over the course of four days. Employees and contractors at a national security laboratory participated, either in a group setting or individually, in an electronic brainstorm to pose solutions to a "wickedly" difficult problem. The data demonstrate that (for this design) individuals perform at least as well as groups in producing quantity of electronic ideas, regardless of brainstorming duration. However, when judged with respect to quality along three dimensions (originality, feasibility, and effectiveness), the individuals significantly ($p<0.05$) out-performed the group working together. When idea quality is used as the benchmark of success, these data indicate that work-relevant challenges are better solved by aggregating electronic individual responses, rather than electronically convening a group. This research suggests that industrial reliance upon electronic problem solving groups should be tempered, and large nominal groups might be the more appropriate vehicle for solving wicked corporate issues.

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INTRODUCTION

Group problem solving and electronic communication are integral to contemporary work organizations, and moreover, represent a ripe research context in which to solve “wicked,” or ill-defined problems, at the very core of industry, as well as the national security environment. Surprisingly, however, very little is empirically known or generally understood about how best to use electronic groups. Before describing our experiment and its relationship to prior literature, we will build the case that a better empirical understanding of electronic groups is needed in order to appropriately leverage available science for solving “wicked” industrial problems.

“Wicked” problems are those problems that by their very definition are so tangled that there is not agreement about their definitions, much less their solutions (see Conklin, 2006, for complete discussion). Wicked problems span multiple disciplines and foci including policy (Rittel & Webber, 2005), business, technical, economic, and political problems (Hutchinson, English, & Mughal, 2002), with examples ranging from solving environmental concerns, to tackling industrial productivity, to addressing crime and terrorism.

Two components of wicked problem solving, including group dynamics and electronic communications, are inherent to most contemporary business environments. First, because there can be no ‘right’ answer or solution without first having agreement about the definition of the problem and the social meaning of a ‘right solution,’ these problems (often) fundamentally relate to the social aspects of groups (Allison, 2006). For the purposes of this paper, groups are defined as “two or more persons who share common goals, whose fates are interdependent, who have a stable relationship, and who recognize that they belong to a group” (Baron & Byrne, 1997, p. 471). Second, as computer networks are increasingly used to conduct business with decreased costs, increased information accessibility, and rapid document, database, and message exchange (Siegel, Dubrovsky, Kiesler, & McGuire, 1986), electronic communication enables a new form of group problem solving that has yet to be well understood, especially as it relates to solving wicked problems.

The need for a better empirical understanding of electronic groups is practically demonstrated through industry’s shift from individual to team contributions, as well as increasing reliance on computer-mediated communications. From a more academic viewpoint, the need for increased understanding of electronic groups can be seen through a vast, non-unified, literature whose findings have yet to be rigorously tested within industrial settings.

According to Kozlowski and Ilgen (2006), organizations worldwide have been shifting from individual jobs to more complex, team-based workflow systems. This shift is being driven by increased competition, consolidation, and innovation which increase needs for the skill diversity, expertise, rapid response, and adaptability that groups may enable (Kozlowski, Gully, Nason, & Smith, 1999). Add to this shift the increased computer availability and broadband communication that enable groups to be distributed across time and space (Bell & Kozlowski, 2002b), and an interesting and complex research area emerges. Kozlowski and Ilgen (2006) have argued that the confluence of such virtual groups with potentially worldwide membership is “inevitable and the source of new research challenges” including “how to harness the emerging technological capability to *enhance* and *evolve* team processes in virtual environments that cut across different cultures” (p. 114).

Computer networks have attained omnipresence within work environments, meaning that electronic communication now offers a novel form of problem solving groups, potentially of interest in solving wicked problems. Over the last 20 years, computer networks have been increasingly used to conduct business because they convey decreased costs with increased information accessibility, and rapid document, database, and message exchange (Siegel, Dubrovsky, Kiesler, & McGuire, 1986). As compared to face-to-face groups, electronic groups allow for more flexible (e.g., non-simultaneous and geographically distributed) forms of intragroup communication. They can also foster stronger group identification (Lea et al, 2001) and adherence to group norms (Spears et al, 1990; although see Douglas & McGarty, 2001).

Interestingly, this networking growth has not fully addressed questions about the decision quality arising from the computer-mediated communication groups or interaction differences between online versus face-to-face meetings. In fact, what empirical evidence is available "raises significant questions about the appropriateness of heavy reliance on computer-mediated communication" for at least some applications (Baltes et al., p. 175).

There is well over half a century of research regarding groups and related topics, however, several broad research challenges remain if computer-mediated groups are to be effectively used to solve wickedly difficult problems. First, identifying what has been quantitatively demonstrated within and between vast and multi-disciplinary literatures is a great challenge (Kozlowski & Ilgen, 2006). These literatures have yet to converge upon group size recommendations or necessary interventions, much less the extant dependencies between group, problem set, and environment yielding optimal problem solving conditions. Second, current research has been largely limited to laboratory, rather than applied, environments. Moreover, the tasks studied within these settings have been primarily constrained to intellective tasks, meaning tasks with a demonstrably correct answer, or tasks with little industrial emphasis. By contrast, applicable organizational challenges are often "wicked" tasks that, because of their ambiguous nature, are more difficult to empirically study. In real-world contexts, groups are seldom aware of whether they have most effectively solved a problem. In fact, the best answer is usually unavailable for teams outside the laboratory, because if that answer were available, there would be no reason to convene a team (Roch & Ayman, 2005).

Noting these challenges and the research infancy of computer-mediated communications, it is clear that a great deal of empirical and theoretical work remains to be accomplished. That work is especially valuable considering the increased costs associated with groups (Greitemeyer, Brodbeck, Schulz-Hardt, Frey, 2006). Thus, industrially-relevant empirical data are important to be able to justify this increased investment and to be able to mitigate potential pitfalls.

GROUP PROBLEM SOLVING THROUGH BRAINSTORMING

Group problem solving performance depends in part on how well groups generate ideas. As the following discussion describes, verbal brainstorming research has spawned questions about electronic brainstorming as well as individual electronic communication efficacy.

Verbal brainstorming is a process where a group of individuals, typically working in the same room, create and share ideas in a free flowing, non-judgmental way. Such groups have typically relied upon Osborn's (1957) brainstorming rules. These include: 1) the more items proposed the better, 2) combine and improve on others' ideas, 3) the wilder the idea the better, 4) do not criticize, and 5) be as clear and concise as possible.

With the arrival of computer mediated communications, people are, naturally, congregating and engaging in group problem solving online. As a result, the literature has grown from initial studies of verbal brainstorming to contemporary electronic brainstorming research. However, even after half a century of study, the bounds of effective verbal brainstorming are yet to be well understood, much less its electronic counterpart.

Popular opinion holds that verbal brainstorming yields more (and better) ideas than the same number of individuals working alone would produce if their results were aggregated (see Furnham, 2000; Guerin, 1986; Osborn, 1957). For example, becoming aware of and/or feeling the presence of others has been shown to provide social facilitation (Bond & Titus, 1983; Guerin, 1986; Zajonc, 1965), and exposure to other individuals' ideas often generates intellectual synergy (Madsen & Finger, 1978) and cognitive stimulation (Dugosh, Paulus, Roland, & Yang, 2000). In addition, claimed advantages of brainstorming include (Furnham, 2000):

- reducing dependence on a single authority figure,
- encouraging open sharing of ideas,
- stimulating participation among group members,
- providing individual safety in a competitive group,
- maximizing output for a short period of time, and
- ensuring a non-evaluative, enjoyable and stimulating environment.

However, investigations into the actual operation of groups involved in verbal brainstorming have uncovered a number of issues, which cast some doubt, or at least caveats, on these optimistic claims.

Issues

Despite popular opinion, verbal brainstorming has been found to result in certain undesirable consequences when compared to individual, or nominal, brainstorming where individuals brainstorm alone and responses are later aggregated. In fact, the data on verbal brainstorming consistently indicate that "sets of individuals working in isolation (nominal groups) outperform interactive groups in both laboratory and organizational settings" (see, e.g., Diehl & Stroebe, 1987; Jablin, 1981; Mullen Johnson, & Salas, 1991; Paulus, Larey, & Ortega, 1995; Taylor, Berry, & Block, 1958). As discussed below, potential verbal brainstorming consequences include production blocking, evaluation apprehension, and social loafing (Kerr & Tindale, 2004).

Blocking

Production blocking is an individual's inability to spontaneously interject ideas without violating group etiquette or breaking the concentration of other members (DeRosa, Smith & Hantula, 2007). That is, if one person is sharing his/her ideas, other members of the group are not able to share their ideas simultaneously. Consequently, their ideas may be "blocked". Nijstad, Stroebe and Lodewijkx (2003) manipulated the delay within which participants were able to contribute ideas. They found that delay length negatively related to performance when the participants were blocked before entering each idea and that unpredictable delays led to fewer trains of thought.

Additionally, those who are silent during a brainstorming session appear to self-censor, forget, or get talked out of a significant number of their ideas (Diehl & Stroebe, 1991).

Evaluation Apprehension

Another negative consequence of verbal brainstorming is evaluation apprehension, which is the tendency for people to hold back their ideas for fear that others will negatively evaluate them (Dennis & Valacich, 1994; Paulus & Yang, 2000). Because verbal brainstorming involves individuals who must, necessarily, share ideas with the group, individuals who are uncomfortable speaking in front of people, or who are afraid that others will negatively judge their ideas, may refrain from contributing to the brainstorming session (Dennis & Valacich, 1993; Dennis & Valacich, 1994; Gallupe, Cooper, Grise & Bastianutti, 1994; Paulus & Yang, 2000; Roy, Gauvin & Limayem, 1996).

Social Loafing

Finally, the group aspect of verbal brainstorming may result in decreased individual investment. This social loafing phenomenon, whereby individuals exert less effort in group projects than they do in equivalent individual work (Connolly, Routhieaux & Schneider, 1993), has been demonstrated across a variety of tasks, from rope pulling to hand clapping to identifying radar signals on a computer screen (Furnham, 2000; Karau & Williams, 1993; Kravitz & Martin, 1986; Latané, Williams & Harkins, 1979).

Can Electronic Brainstorming Mitigate Problems with Traditional Brainstorming?

While verbal brainstorming has been a popular method for eliciting ideas from groups, the process has limitations. Electronic brainstorming (EBS), whereby individuals interact and exchange ideas via computer, has been proposed as an alternative in order to mitigate the negative effects of production blocking, evaluation apprehension, and social loafing. Additionally, EBS offers a potential cost-savings within industrial settings.

EBS limits production blocking, because it allows for simultaneous idea input by multiple group members (Gallupe et al., 1994; Nijstad et al., 2003; Valacich, Dennis & Connolly, 1994). In fact, Valacich and colleagues demonstrated that computer brainstorming participants in production blocking conditions, who could type responses only one at a time, produced four times fewer responses than their counterparts in traditional EBS conditions, who could submit ideas simultaneously.

The evaluation apprehension limitation associated with verbal brainstorming may also be eliminated in EBS, because responses can be submitted anonymously. Cooper, Gallupe, Pollard and Cadbsy (1998) had four groups of participants brainstorm ideas about topics of a controversial nature. The groups included an anonymous EBS group, a non-anonymous EBS group, a verbal brainstorming group, and an individual, or nominal, group. The researchers found that the anonymous EBS group was the most productive overall and produced a larger number of highly controversial ideas than the non-anonymous EBS group.

While EBS seems to constrain the negative effects of production blocking and evaluation apprehension, the research examining EBS's effect on social loafing has reported mixed results. Some research suggests viewing others' ideas decreases the negative effects of social loafing, possibly because participants may be comparing their performance to the performance of their peers (Roy, Gauvin & Limayem, 1996). However, information about others has also been shown to equalize performance levels. This "matching" phenomenon, whereby high performers reduce and low performers increase their respective inputs so that both approach the mean performance, may limit EBS effectiveness (Roy, Gauvin, & Limayem, 1996).

Finally, organizational constraints also suggest an advantage of EBS over verbal brainstorming. In particular, EBS enables shorter meetings, increased participation by remote team members, better documentation via electronic recording, improved access to the meeting records and, importantly, cash savings (Furnham, 2000).

Admittedly, EBS also has some disadvantages. An EBS session could be considered less rich than a face-to-face session, because the electronic medium filters out nonverbal communication. In addition, EBS can not provide rapid feedback as easily, and can reduce communication efficiency, because it takes longer to type than to speak (Dennis & Valacich, 1994). However, despite these disadvantages, the literature indicates that EBS groups almost always outperform verbal brainstorming groups (Gallupe, Dennis, Cooper, Valacich, Bastianutti & Nunamaker, 1992) and members may be more satisfied using electronic brainstorming than when using verbal brainstorming (Gallupe et al., 1992).

While EBS is superior to verbal brainstorming along many facets, the research comparing EBS to nominal brainstorming has produced rather mixed results, thus leaving undetermined how industry can most effectively use technology to solve wicked problems. Some studies have found that EBS is superior to nominal brainstorming (Dennis & Valacich, 1993; Dennis & Valacich, 1994; Paulus & Yang, 2000), while a few others have found that nominal groups were superior to EBS (Barki & Pinosonneault, 2001; Pinosonneault et al., 1999). Still others have found no differences between the two groups (Connolly et al., 1993; Cooper et al., 1998; DeRosa et al., 2007; Dugosh et al., 2000). Moreover, differences between the laboratory environments and applied industrial settings, leave the extension of current empirical findings unclear.

EXPERIMENTAL GOALS

To date most, if not all, of the empirical research in this area has been performed in laboratory settings with college students, leaving its generalizability to industrial applications unclear for several reasons. At least four key differences must be addressed in order to apply the existing research to an industrial setting.

First, groups in typical industrial settings grappling with "wicked" problems may be more inclined to assess the quality of ideas, rather than the quantity of ideas as is typical in the current literature. For example, one great idea that adequately addresses the "wicked" problem will be better than several hundred lesser ideas (for a discussion of the value of quality over quantity, see Rowatt, Nesselroade, Beggan, & Allison, 1997). However, as Barki and Pinsonneault (2001) discuss, the premise that "quantity breeds quality" has underscored most EBS research in spite of the fact that empirical support for this premise is mixed. Thus, it is unclear how current empirical research results, typically reported in terms of quantity of ideas, apply to industrial settings.

Second, most research has examined three- to four-person student groups, rather than larger work teams that leverage diverse skill and knowledge bases. Thus, the extant literature leaves several key industry variables indeterminate, including the interplay of group size, motivation, and diversity of expertise. Within verbal brainstorming research, there is general empirical agreement that verbal brainstorming groups do not perform better than their nominal group counterparts and that individual group member productivity declines as the groups grow larger (Gallupe et al., 1992). By contrast, EBS research suggests that nominal and group electronic performance is similar for smaller groups, but larger groups often outperform their nominal brainstorming counterparts (Dennis & Valacich, 1993, 1994; Dugosh et al., 2000; Gallupe et al., 1991; Valacich et al., 1994). While these findings have been attributed to the stimulating effect of exposure to others' ideas (Dugosh et al., 2000; Nijstad et al., 2003; Paulus & Yang, 2000; although also see Ziegler et al., 2000) and the diversity and heterogeneity of those groups (Schruijer & Mostert, 1997), this research has been limited to a handful of laboratory studies with maximum group sizes of typically only 9-18 people. Thus, they do not fully explore the bounds of this effect for very large, diverse work teams applicable to much of industry. For such groups, it is unclear if and at what size the positive effect of group EBS might be outweighed by potential downfalls. For example, within large online systems, including multi-user communities and online social networks, up to 90% of system activity is from users that read or observe without contributing content (Nielsen, 2006). Additionally, pitfalls of large working groups might include diminished motivation, chasms in understanding between diverse knowledge, technical skill, and ability levels, and ensuing communication melee.

A third key difference that must be addressed in order to apply the existing research to an industrial setting is the kind of problem to be solved. As Paulus and Brown (2007) have stated, "we know of no systematic, controlled study of the brainstorming process in organizations that involves work teams solving real problems" (p. 1). The problem is at least twofold, and results from the focus on intellective tasks in the problem-solving literature, and the reliance on unrelated tasks in the brainstorming literature.

The advantage of using intellective tasks is that response quality is straight-forward to evaluate, because by definition, intellective tasks are those with a defensibly correct answer. By contrast, real-world problems that are wickedly difficult are more difficult to empirically evaluate and rely instead upon time-consuming expert scoring.

Additionally, prototypical brainstorming topics don't necessarily extend to real world problems. Many of the studied topics are less complex and less meaningful to students than would be a "wicked" problem to an invested employee. For example, an often used question in the current literature is the *Thumbs Question* (Bouchard & Hare, 1970; Gallupe et al., 1991), where students are asked to "generate ideas about the practical benefits or difficulties that would arise if everyone had an extra thumb on each hand after next year." Thus, a professional's motivation and cognitive investment in a "wicked" topic, concerning his or her future with the company, might be expected to be very different than a student's investment in the *Thumbs Question*.

Fourth, it is unclear how typical workplace scheduling demands and their accompanying extended brainstorming periods might affect laboratory-based problem-solving outcomes. Within much of industry, it is difficult to schedule 30 (or more) people to brainstorm concurrently, especially when trying to leverage diverse skill sets from multiple departments. Thus, results from short, one-time brainstorming sessions may not generalize to real-world situations where groups of individuals brainstorm over a period of time, often for several days. In addition, the accompanying breaks of extended brainstorming sessions might allow for undefined incubation and motivational affects. Preliminary data are unclear on how these breaks might affect electronic brainstorming outcomes. While brief breaks, of two to five minutes halfway through verbal brainstorming sessions, have been demonstrated to increase the number of ideas generated, this finding has not extended to electronic brainstorming, with Paulus et al. (2006), failing to find a significant effect of breaks during 36-minute brainstorming sessions. Thus, it is unclear how breaks across a several day period might affect electronic brainstorming outcomes.

In conclusion, the extant brainstorming literature has left effective problem-solving empirically indeterminate for extension to industrial applications. As previously outlined, EBS is typically superior to verbal brainstorming; however, the best way to leverage this superiority is currently unclear due to mixed and limited findings comparing EBS to nominal brainstorming, as well as laboratory and industrial differences that call into question the generalizability of available empirical results. The current experiment sought to begin to empirically explore the effectiveness of EBS as compared to nominal brainstorming within the industrial setting at a national research laboratory. It extends the literature by experimentally evaluating the effectiveness of nominal versus group EBS performance within four industrially relevant areas including: 1) response quality (in addition to prototypical quantity scoring), 2) large employee groups of 30 and more, 3) a wickedly difficult, industrially relevant problem, and 4) an extended time period.

METHODS

The experimental design conformed to national statues and regulations with respect to human studies. The design and all experimental materials were approved by Sandia National Laboratories' Human Studies Review Board (HSB; Notice of Approval 6/29/2007).

Participants and Materials

Over the course of four days, 120 employees and contractors at Sandia National Laboratories voluntarily enrolled in the web-based brainstorming experiment. Of the total number that enrolled, 69 participants, including managers, technical employees, and administrative employees, contributed ideas. Of the 69 participants that actively participated and generated ideas, 39 were assigned to the nominal condition and 30 were in the group condition.

The experiment was conducted using a website created and managed by the experimenters. All experimental materials were pre-approved by the institutional HSB, and are available in a separate report (Davidson, Dornburg, Stevens & Forsythe, 2007). After being shown a description of the experiment and participant rights, the registration form explained that continuing with the registration (by creating an account) constituted acknowledgement and acceptance of the conditions of the informed consent materials. When creating the account, the participants were asked to generate user IDs that were anonymous so as to conceal their identities. Following this acknowledgement, demographic information was solicited to enable assignment to appropriate experimental groups.

After registration, participants had the opportunity to view the brainstorming question, respond with ideas, and view the available responses (which would only be their own submissions if they were randomly assigned to the nominal group). Participants were encouraged to read the brainstorming suggestions and rules for using the web site. They were also asked to complete an electronic satisfaction questionnaire at the end of the experiment.

Procedure

Participants were recruited internally through the company's daily news, emails, and an intranet link from the intranet homepage. The participants were randomly assigned to either group or nominal brainstorming conditions. For both conditions, participants were asked to work on a "wicked" problem proposed by the company president. The question read as follows:

> The company president "is interested in the contrast between two models of how organizations relate to their people. One model views people, metaphorically, as just another natural resource, and like other natural resources, to be used (read extracted) for the good of the organization. In that model obtaining people is largely a financial question and the company will derive whatever contributions it can from their skills or experience.
>
> A second model asserts that people are an asset to be continually developed and the investment in their development will yield a dividend to the organization or even to the broader society.
>
> In contrasting these two models, the company president is greatly interested in your thoughts and ideas about:
>
> - how employees establish an identity for themselves in relation to their work environment, i.e., how do they define their *we*, and
> - how to create the appropriate balance between the role of management and the sense of empowerment of employees.
>
> He would like your comments and ideas about the above two questions, and also your insights into
>
> - what environment best supports the identification and development of leaders."

When the participants logged onto the website, the question was displayed at the top of the screen, and they were asked to input their ideas. Those in the nominal condition worked alone and did not see the ideas of other participants. Those in the group condition worked with others and were able to see and build on the ideas of the other members in the group.

Even though the ideas were tagged with the submitter's user ID, the submitter's actual identity was anonymous. The first reason for tagging ideas with the submitter's user ID (but not the participant's actual name) was that anonymity in group brainstorming sessions has been shown to reduce evaluation apprehension (e.g., Cooper et al., 1998). The second reason was that we hoped that by disclosing to the EBS participants the performance of their peers (i.e., the number of ideas submitted by each individual and the quality of those ideas) they would be less likely to engage in social loafing (Karau & Williams, 1993; Roy et al., 1996). Participants were also asked to adhere to the rules of brainstorming per Osborn (1957), and were advised that abusive language and name calling would not be tolerated.

RESULTS

Quantity of Ideas Analysis

The frequency of ideas contributed by each participant was recorded for each day of the experiment. Figure 1 presents the average number of ideas contributed by individuals within the group or nominal conditions. To assess if a difference existed between the research groups (nominal or group) in the number of ideas offered, we performed a repeated measures analysis of variance (ANOVA) on the number of ideas expressed on each of the days by condition (nominal or group). There was a significant effect for the number of ideas expressed on each day (Wilks' Lambda, F (3, 65) = 2.784, p = .048, η_p^2 = .114) in which there were, on average, a larger number of ideas put forward on day one compared to the following three days. There was no significant interaction between the number of ideas per day and condition. Furthermore, there was no significant difference in the number of ideas expressed by the members of the nominal (M = 6.26, SD = 12.85) or group (M = 4.66, SD = 9.21) conditions.

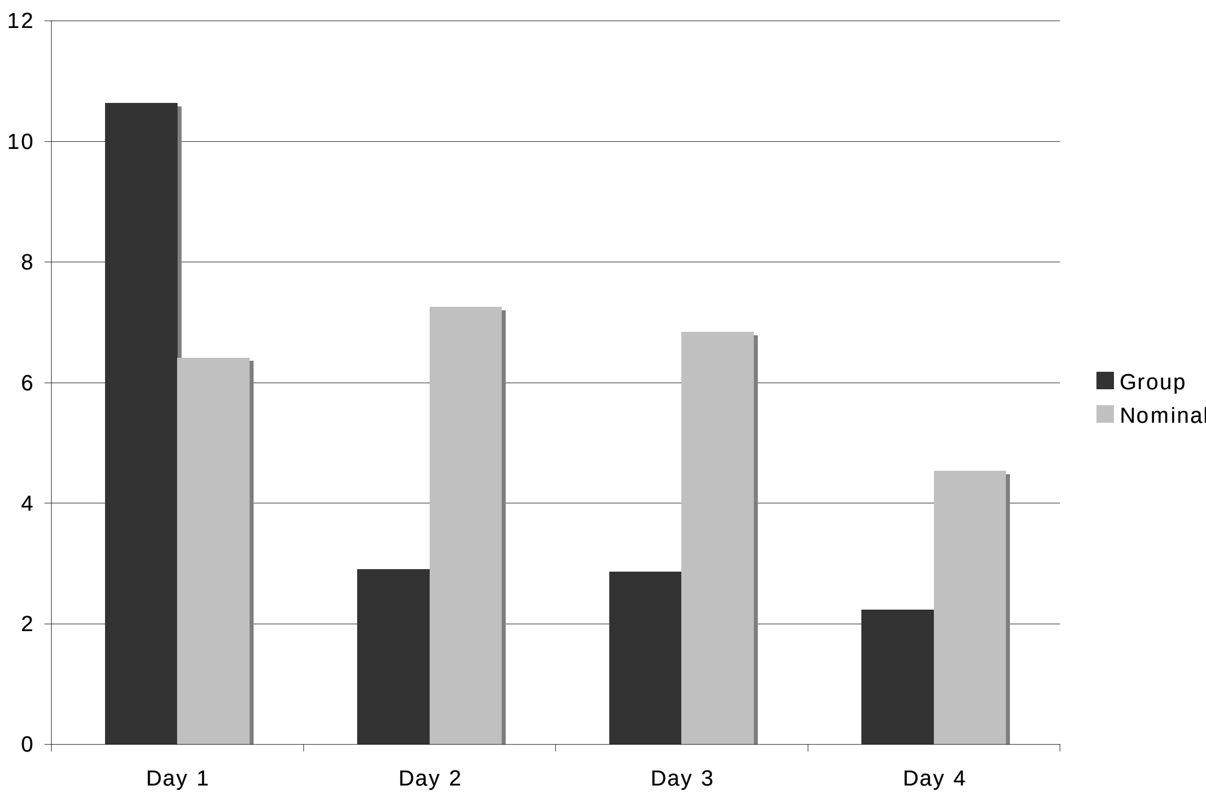

Figure 1. Average number of ideas contributed by members of the group or nominal conditions.

Following this analysis, we wished to further investigate if there was a difference between the research groups in the number of cumulative ideas contributed. The number of cumulative ideas was calculated by adding the number of ideas offered within a single day to the number of ideas offered on each of the previous days. There was no significant interaction between number of cumulative ideas expressed each day and condition. Furthermore, similar to the previous findings, there was no significant difference between the research groups. The average number of cumulative ideas expressed by the nominal condition was 25.05 (SD = 29.08) and by the group condition was 18.63 (SD = 18.18).

In addition, we assessed whether there was a difference in the number of sentences and words generated per day between the research groups. We performed a repeated measures ANOVA on the number of sentences contributed on each of the days by condition (nominal or group). There was a significant difference for the number of sentences per day (Wilks' lambda, F (3, 65) = 2.785, p = .048, η_p^2 = .114) in which there were more sentences produced on the first day compared to the other three days. However, there was no significant interaction between the number of sentences expressed on each day and condition and there was no significant difference in the number of sentences expressed by the group (M = 4.27, SD = .96) and nominal (M = 4.97, SD = .84) conditions. We also performed a repeated measures ANOVA on the number of words provided each day by condition (nominal or group). There was no significant interaction in the number of words written each day by research group. Furthermore, there was no significant difference between days in the number of words submitted and no significant difference in the number of words between the group (M = 80.3, SD = 18.58) and nominal (M = 90.17, SD = 16.30) groups.

Quality of Ideas Analysis

In addition to quantity measures, responses were also examined for quality. In order to do this analysis, responses were summarized into general concepts representing each participant's answer to the "wickedly" difficult question so as to minimize redundancy within each participant's individual entries. Responses unrelated to the question, like those addressing the website design, were not considered in this analysis. Following the example of Barki and Pinsonneault (2001), the quality of ideas was scored according to originality, feasibility, and effectiveness. In this scoring scheme, *originality* referred to the extent to which the idea is novel, or out of the ordinary, *feasibility* referred to the extent to which the idea is precise and the ease with which it can be implemented, given the current context (including available financial resources, infrastructure, time required, legal issues, etc.), and *effectiveness* referred to the extent to which the idea helps to solve the given problem.

Two raters were chosen for their background and experience in operations management and industrial/organizational psychology. The raters came to consensus for each idea using Barki and Pinsonneault's (2001) seven-point Likert Scale in which 1 corresponded to low evidence for the component and 7 corresponded to high evidence for the component.

A two-factor mixed analysis of variance (ANOVA) was conducted to independently evaluate originality, feasibility, and effectiveness. Because we were interested in the most meaningful ideas, we evaluated maximum ratings rather than average ratings. Thus, if a participant received ratings of 3, 4, and 5 for a particular day, the maximum 5 rating was used as that participant's dependent variable.

Originality

Originality of ideas was analyzed using a two-factor fixed ANOVA examining the between-group effect of condition (group and nominal) and the effect of response day (1, 2, 3, and 4). The analysis yielded a significant effect of condition (F (1, 60) = 8.38, p = .005, η_p^2 = .123), indicating that the nominal condition (M = 4.77, SD = 1.04) conferred a significant advantage over the group condition (M = 3.79, SD = 1.42). The analysis did not yield a significant effect of response day (F (3, 60) = 0.03, p = .993, η_p^2 = .001), nor did it yield a significant interaction between condition and response day (F (3, 60) = 1.01, p = .396, η_p^2 = .048).

Feasibility

Feasibility of ideas was analyzed in the same way as originality. Again, this analysis demonstrated a significant effect of condition (F (1, 60) = 4.36, p = .041, η_p^2 = .068), such that the nominal condition (M = 4.05, SD = 1.34) outperformed the group condition (M = 3.14, SD = 1.48). The analysis did not yield a significant effect of response day (F (3, 60) = 0.30, p = .827, η_p^2 = .015), nor did it yield a significant interaction between condition and response day (F (3, 60) = 0.11, p = .955, η_p^2 = .005).

Effectiveness

Effectiveness of ideas was also analyzed using the two-factor ANOVA discussed above. The analysis yielded a significant effect of condition (F (1, 60) = 4.15, p = .046, η_p^2 = .065), such that the nominal condition (M = 4.38, SD = 1.29) outperformed the group condition (M = 3.66, SD = 1.34). This analysis did not yield a significant effect of response day (F (3, 60) = 0.16, p = .922, η_p^2 = .008), nor did it yield a significant interaction between condition and response day (F (3, 60) = 0.58, p = .631, η_p^2 = .028).

DISCUSSION

Our primary empirical finding demonstrates that nominal brainstorming is superior to group brainstorming in at least some industrial contexts. While there was no significant difference in the number of ideas between participants in our nominal and group conditions, our results suggest that the nominal condition tended to produce more ideas than those in the group condition. As might be expected, those in the nominal condition also tended to produce a greater number of sentences and words than those in the group condition, although differences were not significant.

What is more interesting, though, is that the quality of the ideas in the nominal condition was significantly better across all three quality ratings, including originality, feasibility, and effectiveness. These results are interesting for two reasons that will be discussed in turn. First, they are novel, empirical findings suggesting that electronic group effectiveness may be mediated by applied industrial factors, the bounds of which have yet to be fully circumscribed within previous laboratory-based studies. Second, they demonstrate that employees may effectively use computer-mediated nominal brainstorming as a cost effective means to work on wickedly difficult problems.

Applied Industrial Factors

Group decision-making and electronic communication are integral to contemporary work organizations, and offer a yet to be explored research context in which to solve “wicked,” or ill-defined problems. Industry’s shift from individual to team contributions, as well as increasing reliance on computer-mediated communications underscore the practicality of this need. From a more academic viewpoint, the vast, non-unified, group research has yet to be fully applied to industrial settings. According to Paulus and Brown (2007), “There do not exist carefully controlled studies” (p. 1). Thus, the current experiment sought to experimentally extend current laboratory findings to a real-world setting by exploring idea quality, large groups, applied industrial problems, and extended problem solving periods each of which are discussed in turn.

Industrial settings, grappling with “wicked” problems, may be more inclined to assess the quality of ideas, rather than the quantity of ideas typical of the current literature. Thus, the current finding that idea quality in the nominal condition was significantly better (across all three quality ratings, including originality, feasibility, and effectiveness), while quantity was not significantly impacted by experimental condition, has interesting implications. As discussed by Dugosh et al. (2000), high quality ideas have been commonly thought to positively correlate with idea quantity (see, e.g., Dennis, Valacich, Connolly, & Wynne, 1996; Diehl & Stroebe, 1987; Mullen et al., 1991); however, empirical support for this premise is mixed (Chidambaram & Tung, 2005, Barki & Pinsonneault, 2001), and doesn’t hold within the current experimental context. Our finding underscores the need to evaluate both quality and quantity in order to determine the extent to which experimental findings extend to applied settings where quality may be paramount.

The current experiment also speaks to effective group problem-solving size. Previous research has primarily studied three- to four-person student groups, finding that nominal and group electronic performance is similar for smaller groups, but larger electronic groups of 9-18 people often outperform their nominal brainstorming counterparts (Dennis & Valacich, 1993, 1994; Dugosh et al., 2000; Gallupe et al., 1991; Valacich et al., 1994). Thus, the extant literature leaves unclear the bounds of this effect for very large, diverse work teams applicable to much of industry.

There is reason to speculate that very large, diverse work teams might be especially effective for industrial settings due to the potential cognitive stimulation effects offered through the increased knowledge, skill, and ability base that can be leveraged. However, the current literature leaves unclear whether the potential benefits of large group brainstorming might be outweighed by pitfalls of social loafing. In their meta-analysis of the electronic group brainstorming literature, DeRosa et al. (2007) included only two studies with groups of more than 12 members. Similarly, Chidambaram and Tung (2005) have highlighted a need to study groups of 20 or more members because such groups may yield vastly different results than those currently documented in the literature. Accordingly, the current experiment tested employee groups of at least 30 members, finding that the large group did not offer a significant advantage over the aggregation of nominal responses, and thus, that the current literature involving groups of 9-18 does not appear to be scalable within the current context.

In addition to exploring idea quality and large groups, the current experiment also examined an applied industrial problem posed by the company president, rather than an intellective problem or irrelevant question about extra thumbs, as has been common within the previous literature. The current experimental design did not speak directly to how problem complexity and employee investment affect electronic problem solving; however, the participants randomly assigned to both the nominal and group conditions would presumably have viewed the problem as complex enough to warrant their investment. This investment is aptly demonstrated by the participants' willingness to voluntarily (and anonymously) contribute to the experiment without reward.

Finally, the current experiment employed an extended problem-solving period. Because industrial settings often have scheduling demands that preclude the abbreviated, concurrent brainstorming typically used by studies in the current literature, the current experiment expanded the brainstorming session to a four-day period during which individuals could contribute as their schedule allowed. How this applied consideration affected the current findings is unclear, but deserves future examination. Previous researchers (Chidambaram & Tung, 2005; DeSanctis et al., 2000; Hollingshead et al., 1993), have recommended studying groups over longer periods than has been the case in traditional group laboratory studies, suggesting the longer durations may reveal novel outcomes due to "very different kinds of social impact, which would be difficult to replicate and examine in a lab setting" (Chidambaram & Tung, 2005, p. 162). Additionally, the problem-solving breaks afforded by the current experimental design are of future research interest, as previous research has suggested potential related benefits of renewed cognitive stimulation, incubation, and overcoming fixation (see Paulus, Nakui, Putman, & Brown, 2006, for discussion).

Cost Effective Alternative to Solving Wickedly Difficult Problems

In addition to extending the literature, the current findings are also important in that they demonstrate that employees may effectively use computer-mediated nominal brainstorming as a cost effective means to work on wickedly difficult problems. The finding that individuals are more successful than groups in computer-mediated brainstorming suggests a time- and cost-savings potential for companies. Generally, when electronic group brainstorming is compared to verbal brainstorming, it is touted as having the advantages of shorter meetings, increased participation by remote team members, better documentation via electronic recording, improved access to the meeting records and, importantly, cash savings (Furnham, 2000). When there is no longer the mandate that these electronic communications occur concurrently, these advantages would seem to be even greater.

One might also assume that participants in a nominal condition would require less time to contribute ideas as compared to those in a group condition where they would (ideally) read the other postings before giving their ideas. An evaluation of the time savings in this experiment was not empirically addressed, however, nominal brainstorming does allow for increased participation due to somewhat greater scheduling flexibility. In sum, the current findings suggest a novel way to solve wickedly difficult problems offering multiple practical advantages to nominal electronic brainstorming over group brainstorming.

While the current results demonstrate that nominal electronic brainstorming is more effective than its group counterpart, more research will be necessary in order to fully circumscribe the generalizability of this finding to other questions, interfaces, and industrial settings. Future research may compare different computer-mediated technologies, interfaces, and experimental manipulations. For example, a more wiki-like interface might allow users to build off of other people's ideas more easily than the interface used for the current experiment and, thus, outperform a nominal group. Another potential mitigation for large group brainstorming might also include having some kind of facilitator. As one of our participants suggested, "In a real world brainstorm it seems like there should be at least one person in charge with the ability to bring up additional points and keep the ideas flowing when they slow down as they did after the first 2 days here." In a study by Dugosh et al. (2000), she reports that "recent studies have demonstrated that using a facilitator who, among other things, instructs group members to return their focus to the task when they have begun to engage in off-task discussion can greatly enhance the benefits of group brainstorming" (p. 734).

In sum, the current work extends the brainstorming literature by exploring idea quality, large groups, applied industrial questions, and an extended problem-solving time-frame. The applications of this research suggest that large nominal groups are not necessarily the most appropriate vehicles for solving wicked industrial issues. Instead, when idea quality is used as the benchmark of success, these data indicate that work-relevant challenges are better solved by aggregating electronic individual responses, rather than electronically convening a group. Such an approach offers potential cost-saving advantages; however, further research will be necessary to determine how differing electronic technologies might mediate this affect.

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